

# Artificial Gravity Future Plans for ISS

Peter Norsk & Jeff Smith  
NASA JSC & ARC



# Why Use Artificial Gravity?

- NASA's vision for space exploration include DRMs that would send humans beyond LEO for long duration periods.
- Artificial gravity (AG), by reproducing the normal 1G environment, has the unique feature of protecting all physiological systems in all individuals against the effects of weightlessness.
- The selection of the final health protecting countermeasure suites should include consideration for AG, not just traditional methods.
- AG is feasible from an engineering aspect, but more research is required to define the fundamental operating parameters for an AG countermeasure.

# Human Risks of Spaceflight

Grouped by Hazards – 30 Risks & 2 Concerns

## Altered Gravity Level

- Vision alterations
- Renal stone formation
- Sensorimotor alterations
- Bone fracture
- Impaired performance
- Reduced aerobic capacity
- Adverse health effects
- Urinary retention
- Orthostatic intolerance
- Back pain
- Cardiac rhythm problems
- *Effects of medication*
- *Intervertebral disk damage*

## Radiation

- Exposure to space radiation

## Distance from Earth

- Limited in-flight medical capabilities
- Toxic medications

## Isolation

- Adverse cognitive or behavioral conditions
- Performance & behavioral health decrements

## Hostile/Closed Environment– Spacecraft Design

- CO2 exposure
- Inadequate food/nutrition
- Inadequate human-system interaction design
- Injury from dynamic loads
- Injury during EVA
- Celestial dust exposure
- Altered immune response
- Hypobaric hypoxia
- Sleep loss & work overload
- Decompression sickness
- Toxic exposure
- Hearing loss
- Sunlight exposure

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## Isolation

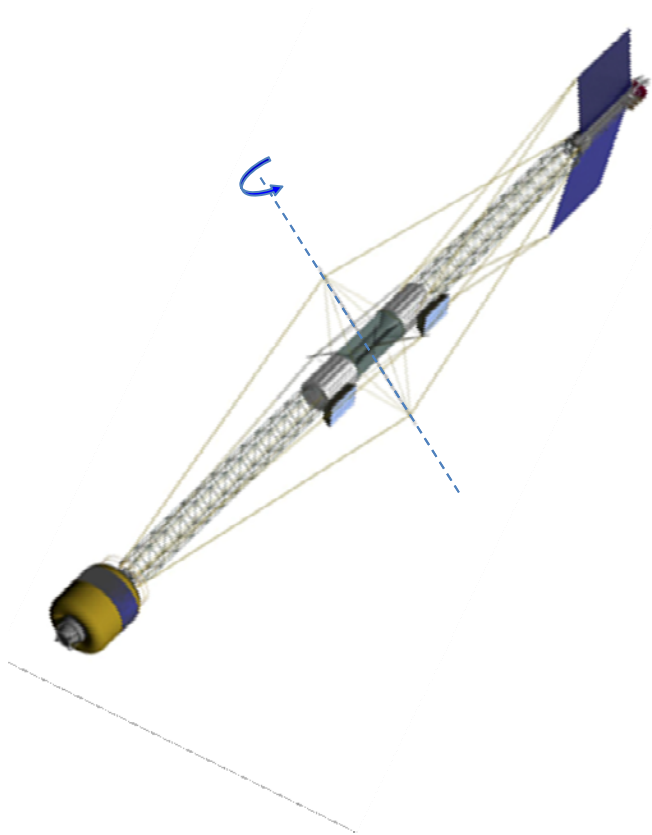
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Risks potentially minimized by artificial gravity

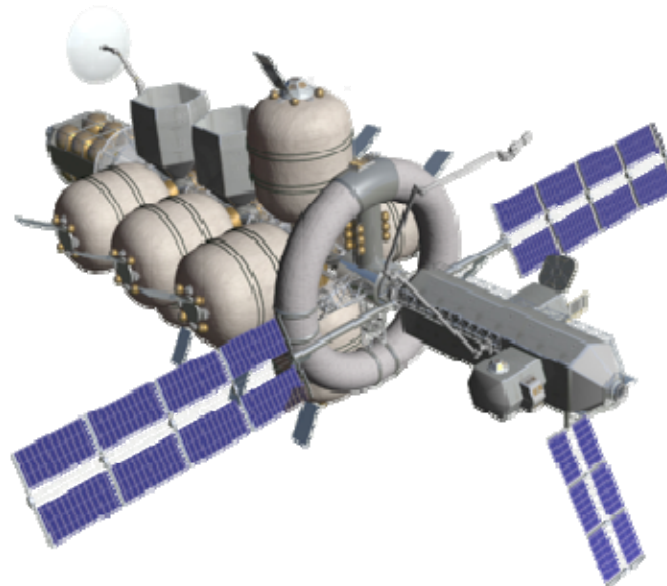


### Rotation of the whole vehicle

e.g. Mars NTR

$$r = 56 \text{ m}$$

$$\omega = 4 \text{ rpm}$$

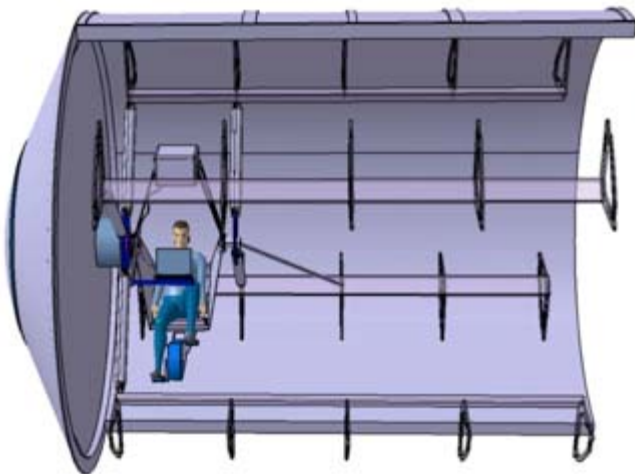


### Rotation of part of the vehicle

e.g. Nautilus-X

$$r = 6 \text{ m}$$

$$\omega = 12 \text{ rpm}$$



### On-board centrifuge

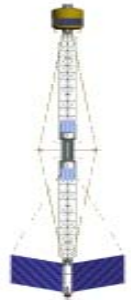
e.g. AGREE

$$r = 1.6 \text{ m}$$

$$\omega = 24 \text{ rpm}$$



# Whole vehicle rotation configurations

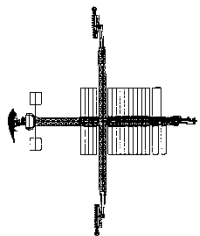


**"Free Baton"**

- Hab counterweighted by reactor/power conversion systems
- Entire vehicle rotates
- Vehicle pointing provides majority of thrust vector control (TVC)

- *No rotating joints, power connections, fluid connections, etc.*
- Power conversion systems operate in g-"field"

- *Vehicle angular momentum must be continuously vectored for TVC*
- Thermal radiators in g-"field"
- Crew ingress/egress

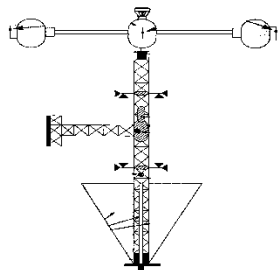


**"Ox Cart"**

- Hab counterweighted by reactor/power conversion systems
- Thrusters, despun, gimbaled for TVC

- *Thrust vectoring decoupled from rotational angular momentum*
- Power conversion systems operate in g-"field"

- *Megawatt-level power, prop transfer across rotating joints*
- Potential cyclical loading of rotating joints
- Thermal radiators in g-"field"
- Crew ingress/egress

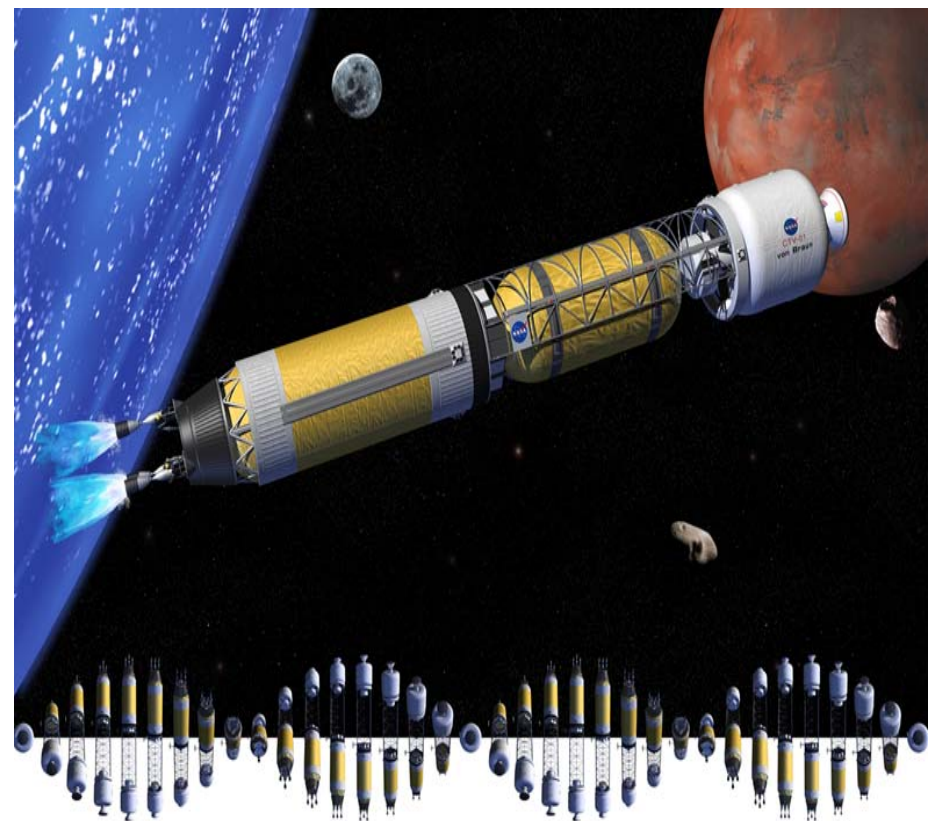
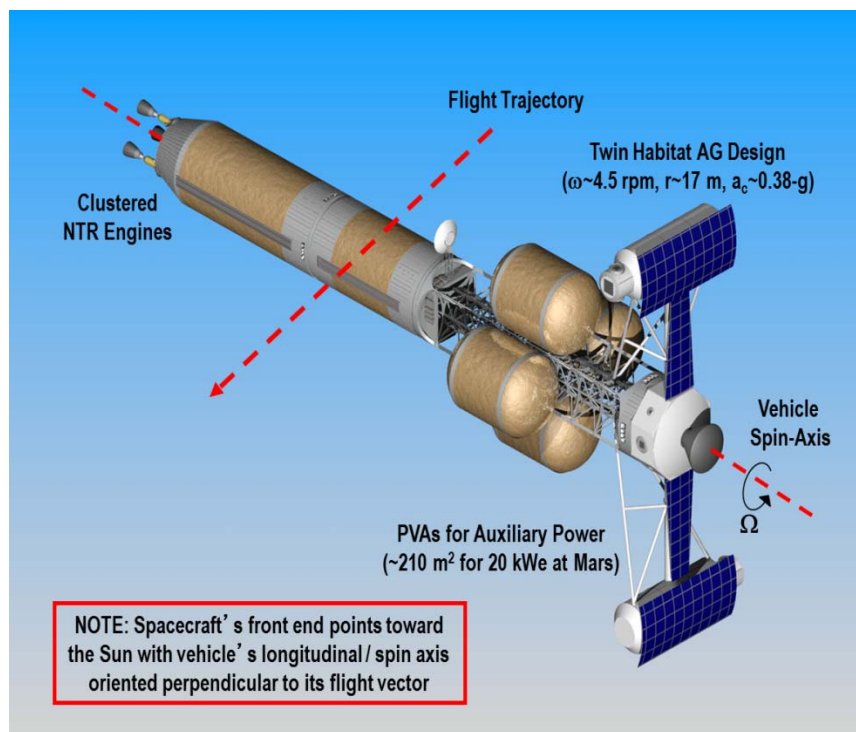


**"Beanle Cap"**

- Split habitation volumes for counterweights
- Reactor/power conversion systems, thrusters in zero-g
- Thrusters gimbaled for TVC

- *Thrust vectoring decoupled from rotational angular momentum*
- Thermal radiators in zero-g

- *Inefficiencies in duplicating habitation systems, crew transfer between them*
- Potential cyclical loading of rotating joints
- Power conversion systems operate in zero-g
- *Kilowatt-level power transmission across rotating joints*



# Summary: Effectiveness of AG Prescription

	main hypotheses*	finding	comment
<b>Bone</b>	↔ bone mineral density ↑ bone homeostasis	as expected not supported	short duration insufficient loading?
<b>Muscle</b>	↑ strength ↑ fiber-type homeostasis ↓ muscle atrophy	supported supported supported	
<b>Cardio</b>	↑ orthostatic tolerance ↑ sympathetic response ↑ aerobic capacity	supported supported supported	
<b>Neuro</b>	↔ CDP, OCR ↔ SVV ↑ proprioceptive reflexes	as expected not supported supported	no adverse response spatial disorientation?
<b>Immuno</b>	↑ stress marker response	not supported	no Δ either group
<b>Psych</b>	↔ cognitive performance	supported?	↓ trend, but low n

\*expected outcome of Treatment Subjects when compared to Control Subjects

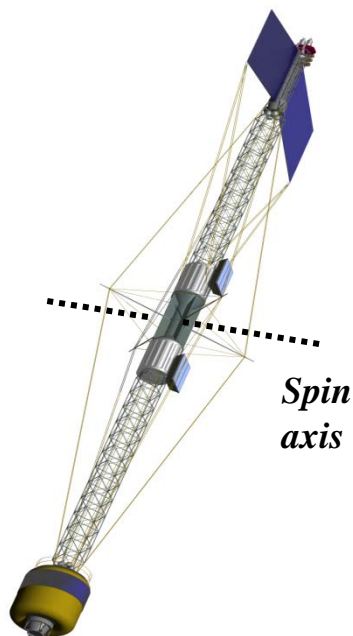




# 2014 Artificial Gravity Workshop

Chairs:

William Paloski, Ph.D., and John B. Charles, Ph.D.



## White Paper

**Ames Research Center, February 19 – 20, 2014**

## Editorial Board:

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Ronita Cromwell, Ph.D., Justin Kugler, Charlene Gilbert, and David  
Baumann, M.Sc.



## **Conclusion and Next Steps**

The workshop showed that there is a broad interest among engineers, researchers, managers and international partners to pursue AG as a countermeasure for future long duration manned deep space missions. The key conclusions and next steps are:



- A feasibility study anticipating a 1-G continuous AG-level by spinning the whole vehicle on a trip to Mars with a crew of 4 in an 8.3 m radius habitat and radius of rotation 56 m has shown to be possible.
- The physiological requirements to engineering should be defined and constitute answers to the following questions: 1) Intermittent or continuous AG? 2) if intermittent: G-levels, durations, radius of rotation? 3) if continuous: Minimum G-level, radius of rotation? These answers are pivotal for determining feasibility of AG.



- An AG peer reviewed research project should be established according to the management aspects in fig. 2 on an international basis exploiting ground based AG facilities worldwide in a coordinated fashion.
- The main physiological drivers for AG during long duration space missions should be defined (such as the VIIP syndrome) and the G-dose physiological response curve established to define thresholds etc.
- Considerations as to whether an intra-vehicular human centrifuge should be installed on ISS and/or an additional centrifuge module attached to ISS.



- The physical side effects of spinning (Coriolis force, cross coupling effects etc., motion sickness) should be determined for deciding optimal spinning radius and G-level in close cooperation with engineers.
- The critical research path based on public international solicitations should be established with parallel tracks towards 2022 involving 1) animal centrifuge research a) ground based and b) on ISS, 2) human ground based bed rest and SAHC research, 3) human ground based long arm centrifugation and long duration (days) research, 4) ground based cell culture centrifugation research, and 5) ISS cell culture centrifugation research.



# Conclusions

- Broad interest to pursue AG
- Continuous whole space habitat spinning possible
- Before 2022, life science requirements should be defined
- Three scenarios: Intra -, extra-, & whole-vehicle rotation
- Critical research path (international):
  - 1) Animal ground and space,
  - 2) human ground,
  - 3) cell culture ground and space

## AG Project Status

- **March 2014** – HRP approval to initiate the Artificial Gravity project to develop evidence-based recommendations for or against the use of AG in deep space transit vehicles by 2022.
- **September 2014** – Creation of Internat'l AG Working Group as a sub-group of the International Countermeasure Group
- **December 2014** – External Advisory Panel of AG experts approval of Evidence Report on artificial gravity.
- **April 2015** – HRP approval of AG Research Plan.
- **May 2015** – NASA Request for Information (RFI) on Biological & Physiological Effects of Partial Gravity.

# AG Research Plan

## 1. AG Level

- G dose-physiological response relationship
- Humans, rodents, cells
- Parabolic flight, centrifugation, suspension, bioreactor, computational models

## 2. AG Duration and Frequency

- Continuous rotation
- Intermittent rotation

## 3. Health Consequences of AG

- Cross-coupled and Coriolis accelerations
- Gravity gradient
- Intracranial pressure

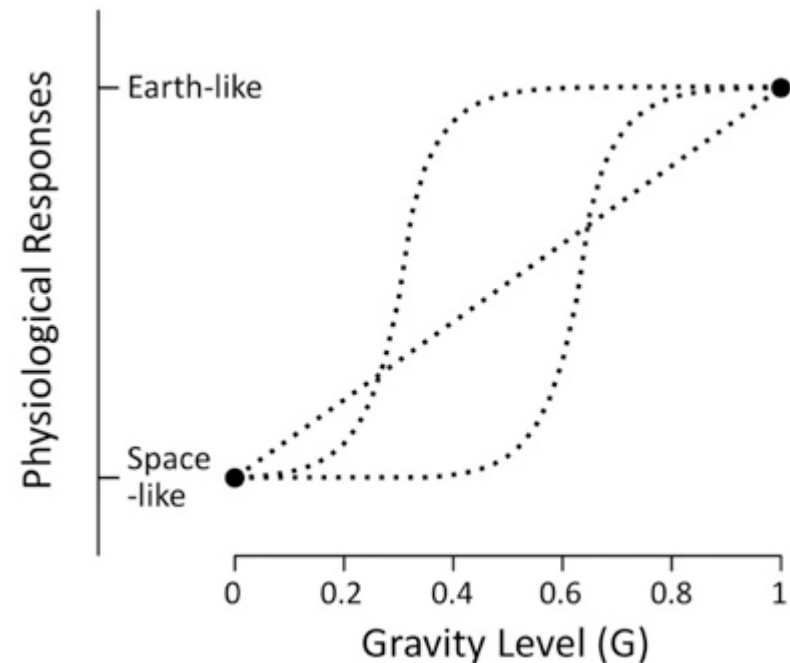
## 4. Validation of AG Prescription

- Comparison between animal centrifugation on the ground and in space
- Tests of a human centrifuge in space

# Detailed Research Plan

## 1. AG Level

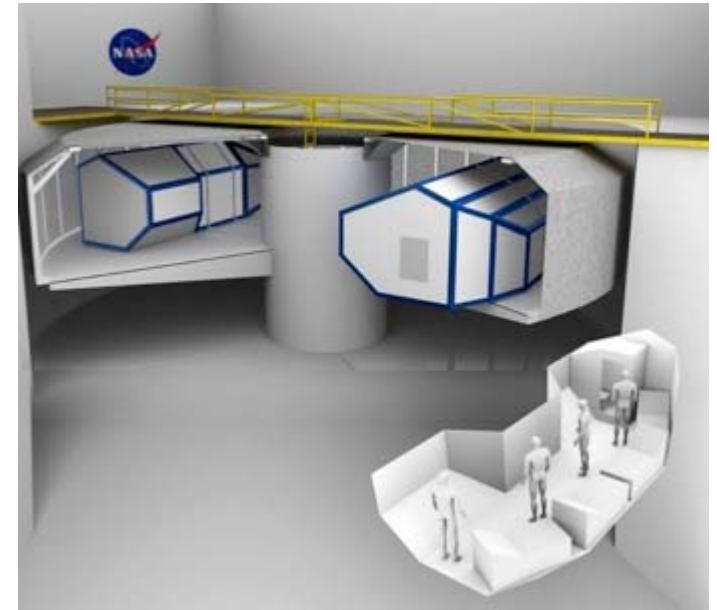
- G dose-physiological response relationship
- Humans, rats, cells, computational models
- Ground-based studies:
  - Bioreactor
  - Centrifugation with or without unloading
  - Parabolic flight
  - Digital Astronaut Project



# Detailed Research Plan (cont'd)

## 2. AG Duration & Frequency

- Continuous rotation
  - Large-radius centrifuge / habitat
- Intermittent rotation
  - Short-radius centrifugation during bed rest / dry immersion

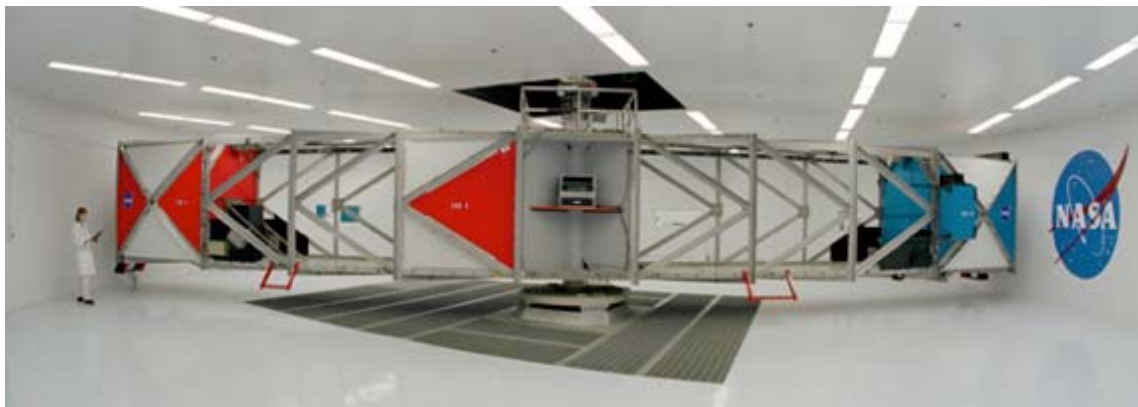




## Detailed Research Plan (cont'd)

### 3. Health Consequences of AG

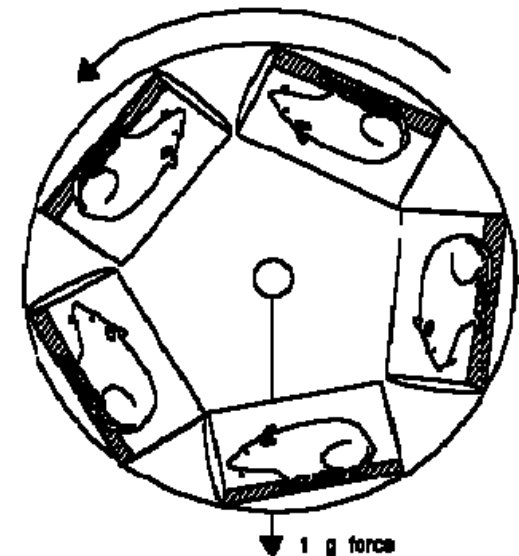
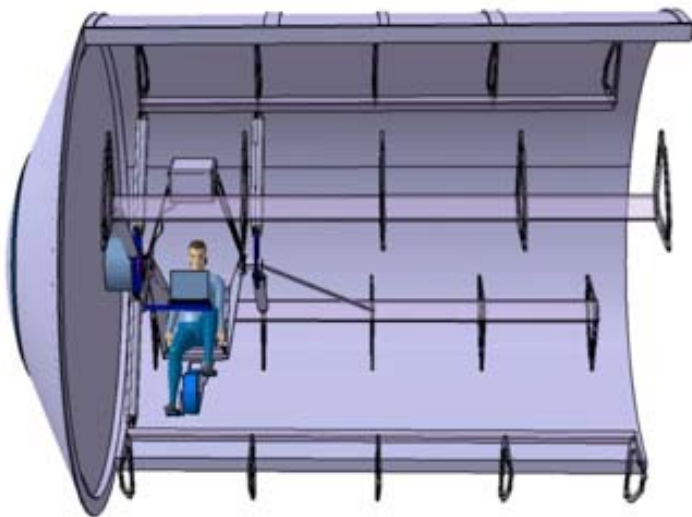
- Cross-coupled & Coriolis accelerations
  - Rotating chair
  - Slow Rotation Room
- Gravity gradient
  - Large-radius centrifuge
- Intracranial pressure
  - Large-radius centrifuge



## Detailed Research Plan (cont'd)

### 4. Validation of AG Prescription

- Comparison between animal centrifugation on the ground and in space
- Space operations of a human short-radius centrifuge
- Tests of a human centrifuge in space





## AG-Animal Models (Ground & Space)

### Overview of Mouse Habitat Cage Unit

